High Power Density, Lightweight Thermoelectric Metamaterials for Energy Harvesting

Completed Technology Project (2013 - 2014)

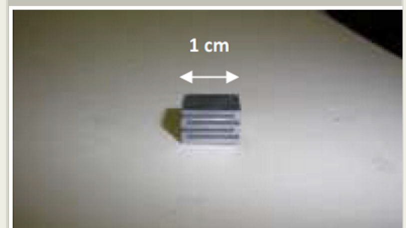
Project Introduction

Thermoelectric energy harvesting utilizes materials that generate an electrical current when subjected to a temperature gradient, or simply, a hot and cold source of heat. The temperature gradient source is irrelevant resulting in an exceptionally diverse energy harvesting device. The efficiency of thermoelectric generators however, is lower than comparable alternative energy sources such as photovoltaics. Efforts to increase the efficiency have focused primarily on creating new materials through solid state chemistry. Some minor advances have been made; however, in order to meet the needs of NASA mission activities, the efficiency of thermoelectric generators needs to be increased substantially. Moreover, future power generation systems should exhibit a high power density (watts per area and watts per mass), reduced weight and become a transformational enabling technology that delivers affordable and abundant power. Consequently, this research proposal encompasses a method to substantially increase the thermoelectric power generation efficiency and power density while simultaneously decreasing the thermoelectric material weight. In conclusion, the primary goal of this proposal is to fabricate and test a lightweight thermoelectric metamaterial designed to exhibit high energy conversion efficiency and power density through engineered control over the thermal properties. Additional research goals include the advancement of theoretical understanding of thermoelectric metamaterials, development of computational capabilities for optimization and testing of an actual thermoelectric metamaterial module.

The objective of this project is to precisely control the flow of thermal, electrical and thermoelectrical energy by advancing the development of a new class of thermoelectric (TE) materials. The goals of this project are to (1) optimize metamaterial structure so power generation efficiency can be increased; (2) synthesize high power factor materials once deemed inappropriate for efficient thermoelectrical operation due to their large thermal conductivity; (3) assemble and test a thermoelectric module with an optimized TE metamaterial; and then finally, (4) characterize, on a micron scale, the thermal behavior of the metamaterial. Thermal behavior must be experimentally characterized, under a variety of operating conditions, using a research grade infrared (IR) camera. The results will enable validation studies with finite element models.

Anticipated Benefits

The lightweight thermoelectric metamaterials for energy harvesting will benefit NASA unfunded and planned missions by enabling the ability to harvest and utilize energy.



TE metamaterial fabricated from chromium and thermoset polymer. Heat flows perpendicular to the layers while electrical currents are isolated to the metal.

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The high efficiency energy conversion of thermoelectric materials will directly benefit NASA funded mission because power and reliability requirements continue to increase for NASA applications, the need for has become a significant challenge, as reflected in NASA's Grand Challenge of "Affordable and Abundant Power." Thermoelectric (TE) devices represent a promising technology for many energy conversion applications. The technology will substantially increase the efficiency of thermoelectric generators, increase power generation from existing thermal sources and reduced thermoelectric generator weight. In addition to thermal conductivity tuning, the dielectric material is also the source of the weight reduction and high power density which are primary issues on most NASA missions. Experimental measurements will be obtained to provide relevant transport properties and power generation efficiency.

The modular TE device boasts numerous benefits but is especially unique in its fuel source; namely, virtually any source of heat. A distinct advantage of thermal fuel sources is their fairly stable availability unlike the cyclic interruptions that often plague other alternative energy conversion technologies. For example, unused thermal sources are plentiful on advanced aerospace systems such as rocket engines, spacecraft electronics and general on-board flight systems. NASA has recognized this fact long ago and is not only a prime user of TE devices but a research collaborator on many TE projects. TE modules are also scalable meaning they may be assembled in tiny miniaturized form or grouped in arrays that cover large areas. The advent of autonomous swarms of sensor arrays in addition to isolated transducers and sensors require reliable power, an ideal application of TE modules that eliminates the need for batteries and/or external wiring from a remote power source. From the standpoint of high-tech systems in general, the need for cheap efficient reliable power applies equally well. future power generation systems should exhibit a high power density(watts per area and watts per mass), reduced weight and become a transformational enabling technology that delivers affordable and abundant power.

Benefits to the commercial space industry would be similar to those that benefit NASA, and correspondingly address the need for an inexpensive efficient reliable energy source.

Improving the efficiency of TE performance would benefit not only NASA but to other government agencies (Department of Defense, Homeland Security, etc.) that have the need to increase and improve the ability to harvest and utilize energy.

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Center / Facility:

Stennis Space Center (SSC)

Responsible Program:

Center Innovation Fund: SSC CIF

Project Management

Program Director:

Michael R Lapointe

Program Manager:

Ramona E Travis

Project Manager:

Lauren W Underwood

Principal Investigator:

Scott L Jensen

Co-Investigator:

Nick Nugent

Center Innovation Fund: SSC CIF

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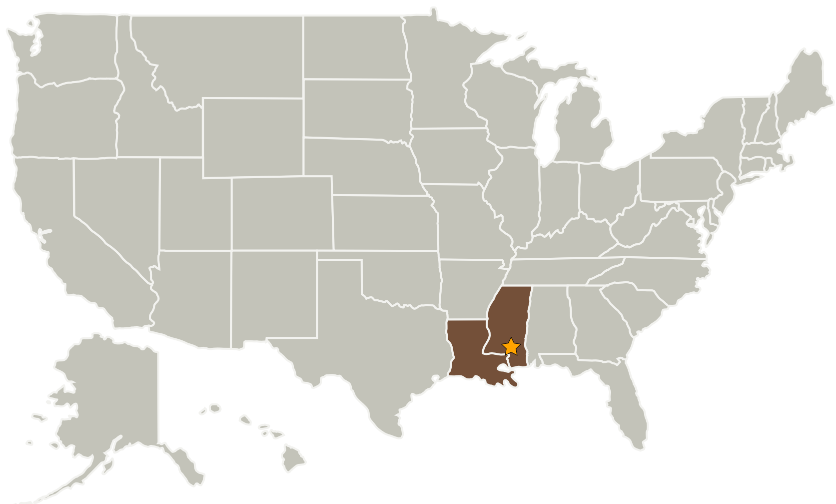
Primary U.S. Work Locations and Key Partners

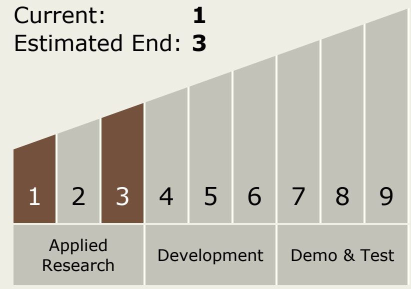


Organizations Performing Work	Role	Type	Location
★Stennis Space Center(SSC)	Lead Organization	NASA Center	Stennis Space Center, Mississippi
Loyola University New Orleans	Supporting Organization	Academia	New Orleans, Louisiana
University of New Orleans	Supporting Organization	Academia	New Orleans, Louisiana

Primary U.S. Work Locations	
Louisiana	Mississippi

Technology Maturity (TRL)

Start: **1**
Current: **1**
Estimated End: **3**

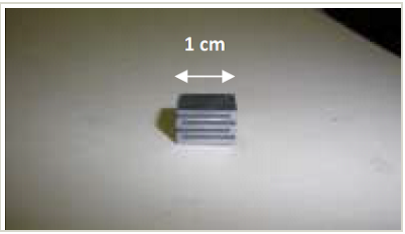


Technology Areas

Primary:

- TX12 Materials, Structures, Mechanical Systems, and Manufacturing
  └ TX12.1 Materials
    └ TX12.1.6 Materials for Electrical Power Generation, Energy Storage, Power Distribution and Electrical Machines

Images



TE metamaterial fabricated from chromium and thermoset polymer. Heat flows perpendicular to the layers while electrical currents

TE metamaterial fabricated from chromium and thermoset polymer. Heat flows perpendicular to the layers while electrical currents are isolated to the metal.
(https://techport.nasa.gov/image/2775)